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GEOCHEMISTRY

Results of U–Pb LA–ICP–MS Dating of Detrital Zircons from Ediacaran–Early Cambrian Deposits of the Eastern Part of the Baltic Monoclise

A. S. Ivleva[a], V. N. Podkovyrov[b], V. B. Ershova[a], O. A. Anfinson[c], A. K. Khudoley[a], P. V. Fedorov[a], Corresponding Member of the RAS A. V. Maslov[d], and D. Yu. Zdobin[a]

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Abstract—Here we present the results of U–Pb LA–ICP–MS dating of detrital zircons from the Ediacaran–Early Cambrian deposits of the eastern part of the Baltic monoclise (Leningrad Region). The obtained age spectra of the detrital zircons suggest that, in the Ediacaran–Early Cambrian, the main clastic material source to the northwest of the Russian Platform was the Baltic Shield. Then in the Early Cambrian along with the Baltic Shield provenance, a clastic source from the Timanian margin of Baltica (northeast in modern coordinates) contributed to the deposits. The obtained data either somewhat set limits of the Timanian orogen formation as older than the previously suggested Middle Cambrian (about 510 Ma), based on the "absence of a Proto–Uralian–Timanian provenance signal" in the Sablino Formation rocks in the south Ladoga, or suggest another rearrangement of detritus transportation paths at the end of Stage 3 (Atdabanian).

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As a complement to the common litho- and biostratigraphic methods, U–Pb dating of detrital zircon from clastic sediments may provide essential information for deciphering the history of formation of a sedimentary basin and, particularly, the ages of rocks in a source area [1–3]. New U–Pb data obtained on detrital zircons from the Ediacaran–Early Cambrian deposits of the Baltic monoclise east (Fig. 1) substantially supplement earlier results acquired from the base of the sedimentary cover of the northwestern part of the Russian Platform [4–9]: these data demonstrate that during the Ediacaran–Early Cambrian transition the area under consideration experienced significant change in directions of clastic material transport. While during the Ediacaran the Baltic Shield was the dominant debris source, in the very beginning of the Early Cambrian, the Timanian margin of Baltica began to contribute considerably to the formation of the Baltic monoclise sedimentary cover.

The Ediacaran sediments (Starorussa Formation of the Redkin Horizon, Vasilieostrov and Voronkovo Formations of the Kotlin Horizon) in the studied territory, resting unconformably upon buried fragments of the basement, are composed mainly of clays, siltstone, and sandstone [10, 11] (Fig. 2). The sediments ascribed to the Starorussa Formation (up to 47 m thick) are unevenly grained sandstones with layers of gritstones and conglomerate; its upper part is dominated by greenish gray clay [11, 12]. With an erosion surface at its roof, the Starorussa Formation is overlain by the Vasilieostrov Formation, up to 80 m thick. The lower part of the latter comprises mainly unevenly (up to coarse) grained greenish gray feldspar–quartz sandstones, alternating with siltstone and clays. The latter commonly form thin layers with the thickness occasionally reaching 1.5–2.0 m. Upwards the sandstone becomes more clayey and transits into a unit of laminated clay [11, 13]. The Vasilieostrov sediments are conformably covered by speckled clay and siltstone of the Voronkovo Formation (up to 20 m), which contain at their base psammitic and gravel grains and, in its upper part, fine-grained poorly lithified quartz sandstone and siltstone [11].

The Fortunian (Lower Cambrian) section begins with the Lomonosov Formation (4–23 m): it consists of sandstone, siltstone, and clays. The transition from the Ediacaran Voronkovo Formation to psammitic–pelitic Lomonosov sediments is not well pronounced: a basal unconformity at the Lomonosov Fm bottom may be recognized only in sections westerly of St. Petersburg [11]. The above occurring Siverskaya Formation deposits (70–120 m) encompass bluish tabular laminated clay. Those clays are roofed with the erosion surface, which is overlain in the west of Leningrad Region and Estonia by transgressive greenish gray clays and fine-grained sandstone of the Lukatin For-

[a] *St. Petersburg State University, St. Petersburg, Russia*
[b] *Institute of Precambrian Geology and Geochronology, St. Petersburg, Russia*
[c] *University of Texas at Austin, Austin, Texas USA*
[d] *Institute of Geology and Geochemistry, Ural Branch of Russian Academy of Sciences, Pochtovy per. 7, Yekaterinburg, 620151 Russia*
e-mail: @ias.ivleva@gmail.com

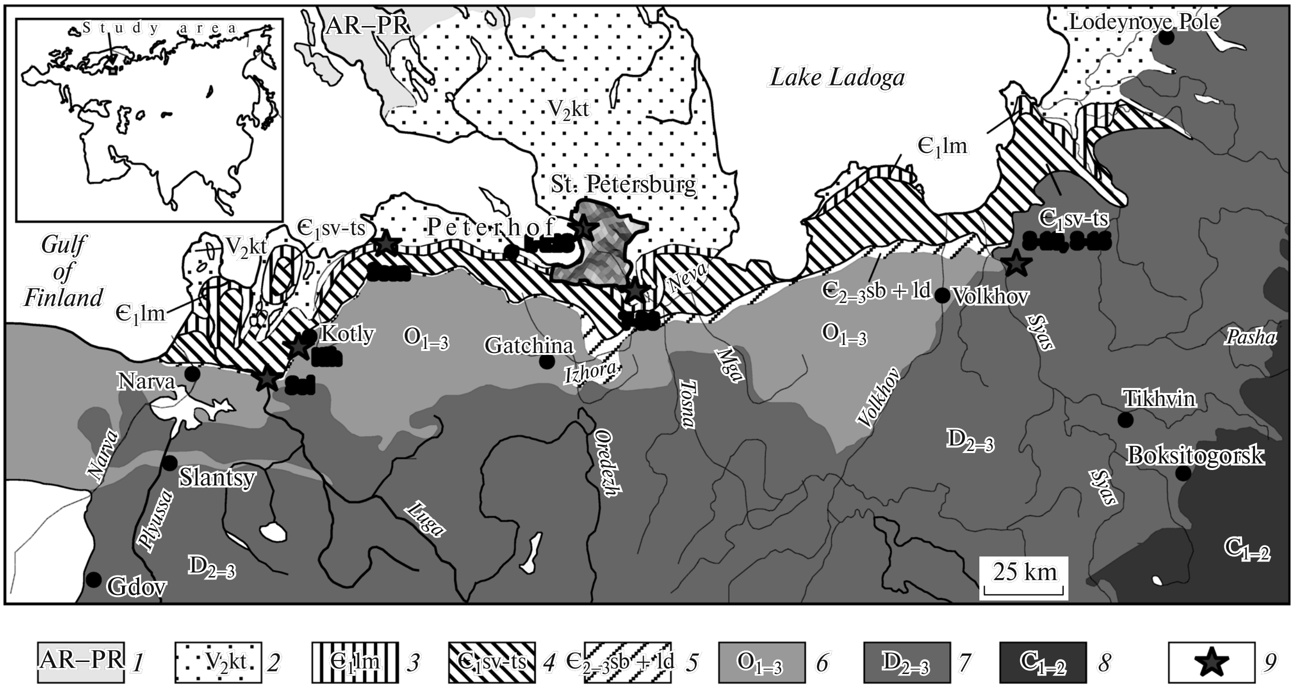

Fig. 1. Simplified geological map of the eastern part of the Baltic monoclise with sampling localities. *1*, Archaean–Proterozoic; *2*, Ediacaran, Kotlin Horizon; Lower Cambrian: *3*, Lomonosov Formation; *4*, Siverskaya, Lukatin, and Tiskres Formations; *5*, Middle–Upper Cambrian, Sablino and Ladoga Formations; *6*, Ordovician; *7*, Middle–Upper Devonian; *8*, Carboniferous, nondivided; *9*, sampling localities for detrital zircon dating.

mation (Atdabanian/Stage 3 of the Lower Cambrian), 5–6 m thick. The Tiskres Formation (12–15 m) comprising massive light-colored sandstone interbedding with silty clays belongs to the same Stage 3.

Five samples for U–Pb LA–ICP–MS detrital zircons dating have been collected at various levels of the Ediacaran–Early Cambrian sequence (Fig. 2). Preliminary sample treatment and detrital zircon separation from the Starorussa and Vasilieostrov Ediacaran sandstone (samples T-36, L-118, and Sosn) as well as from Lomonosov, Lukatin, and Tiskres formations of the Lower Cambrian (samples 8–10, 8–16, Kih, and Sol) were performed at the Institute of Precambrian Geology and Geochronology, Russian Academy of Sciences, following standard procedures. U–Pb LA–ICP–MS analyses were carried out at the University of Texas at Austin (United States) applying a Thermo ELEMENT 2 mass spectrometer coupled with a 193 nm Excimer Laser ablation unit. The analytical error is given at the $\pm 2\sigma$ level. In cases when the age of a detrital zircon exceeds 1.0 Ga, the final results have been calculated using the $^{207}Pb/^{206}Pb$ ratio and younger ages were assessed on $^{206}Pb/^{238}U$. Diagrams have been plotted applying the ISOPLOT 4.0 program. According to the existing approach [3], only results with discordance of <30% have been taken into consideration. The zircon provenance ages are given in Fig. 3.

The upper Starorussa Formation sample T-36, collected from the Utkina Zavod borehole, is dominated by zircons of Palaeoproterozoic age (92%) forming peaks at 2069, 1998, 1924, 1896, and 1796 Ma. Some zircons yielded Archaean and Mesoproterozoic ages, but the former do not cluster into any significant peak, while the latter concentrate at 1575 Ma. The detrital zircon population from sample L-118 (borehole No.3, Lakhta construction plot) picked at the bottom of the Vasileostrov Formation demonstrate major Palaeoproterozoic peaks (64%) at 1885 and 1627 Ma, while the Mesoproterozoic results (35%) form a pronounced peak at 1584 Ma. As in sample T-36, in this sample the Archaean results are solitary. The Sosn sample (borehole 4/10, Sosnovka settlement) collected at about the same level of the section is dominated by zircons of Palaeoproterozoic age (about 73%, peaks at 1879, 1827, 1682, and 1614 Ma). The number of Mesoproterozoic zircons reaches 25% with a distinct peak at 1590 Ma. Archaean zircons in this sample are scarce.

Two samples (8–10 and 8–16) were collected from the loose light gray feldspar–quartz sandstone of the Lomonosov Fm. (Korovino borehole, lower reaches of the Syas River). Those two yielded quite similar detrital zircons ages; thus, in Fig. 3 they are plotted together. The proportions of Palaeoproterozoic and Mesoproterozoic results here are in the ranges 20–55% and 24–27%, respectively. They have clusters at about 1900, 1870, 1550, and 1260 Ma. The Neoprot-

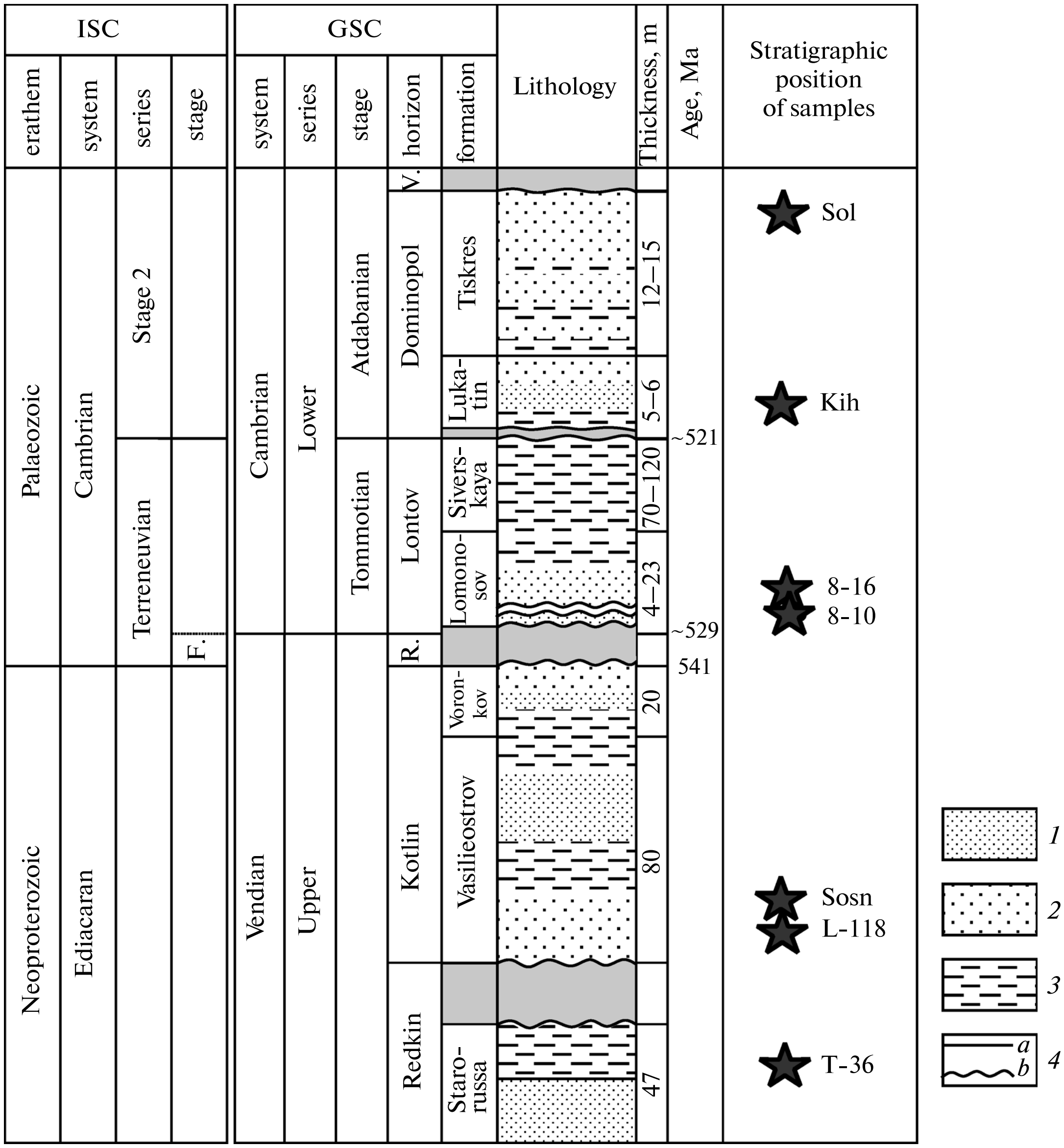

Fig. 2. Geological section of the Ediacaran–Lower Cambrian deposits of the eastern part of the Baltic monoclise (after [4, 5], modified) and sample position. *1*, Sandstone; *2*, siltstone; *3*, clay; *4*, stratigraphic contacts: *a*, confromable, *b*, unconformable. ISC, International Stratigraphic Chart; GSC, General Stratigraphic Chart of Russia; F, Fortunian Stage; R, Rovno Horizon; V, Vergal Horizon. Rest of legend as in Fig. 1.

erozoic zircons (25–36%) form peaks at about 630, 600, and 565 Ma, while the Cambrian peak appears at about 534 Ma. In sample Kih (excavation on the right bank of the Kikhtolka River), the zircon population is dominated by Mesoproterozoic grains (53%) with pronounced peaks at 1101, 1221, 1257, 1450, 1501, and 1553 Ma; the Palaeoproterozoic zircons (about 32%) are grouped at 1617, 1684, 1756, 1945, 1987, and 2140 Ma. The Neoproterozoic zircons cluster at 930, 636, and 568 Ma. The Cambrian results constitute about 3% averaging about 531 Ma. The Tiskres Fm. massive fine-grained sandstone (sample Sol, trench on the left bank of the Solka River near the village of Kili) produced a detrital zircon population dominated by Mesoproterozoic grains (54%) grouped at 1507, 1456, 1327, 1222, 1076, and 1025 Ma. The Palaeoproterozoic zircons make up about 30% of the population, producing peaks at 2024, 1960, 1837, 1803, 1679, and 1618 Ma. Only two Archaean peaks are observed at 2738 and 2711 Ma. No significant Neoproterozoic cluster has been revealed, while the few Cambrian zircons are grouped at 535 Ma.

The obtained data demonstrate that the patterns of detrital zircon ages from the Ediacaran and Early Cambrian sediments of the eastern part of the Baltic monoclise are substantially discrepant. The Ediacaran detrital populations are dominated by the Palaeoproterozoic with subordinate Mesoproterozoic ages and a

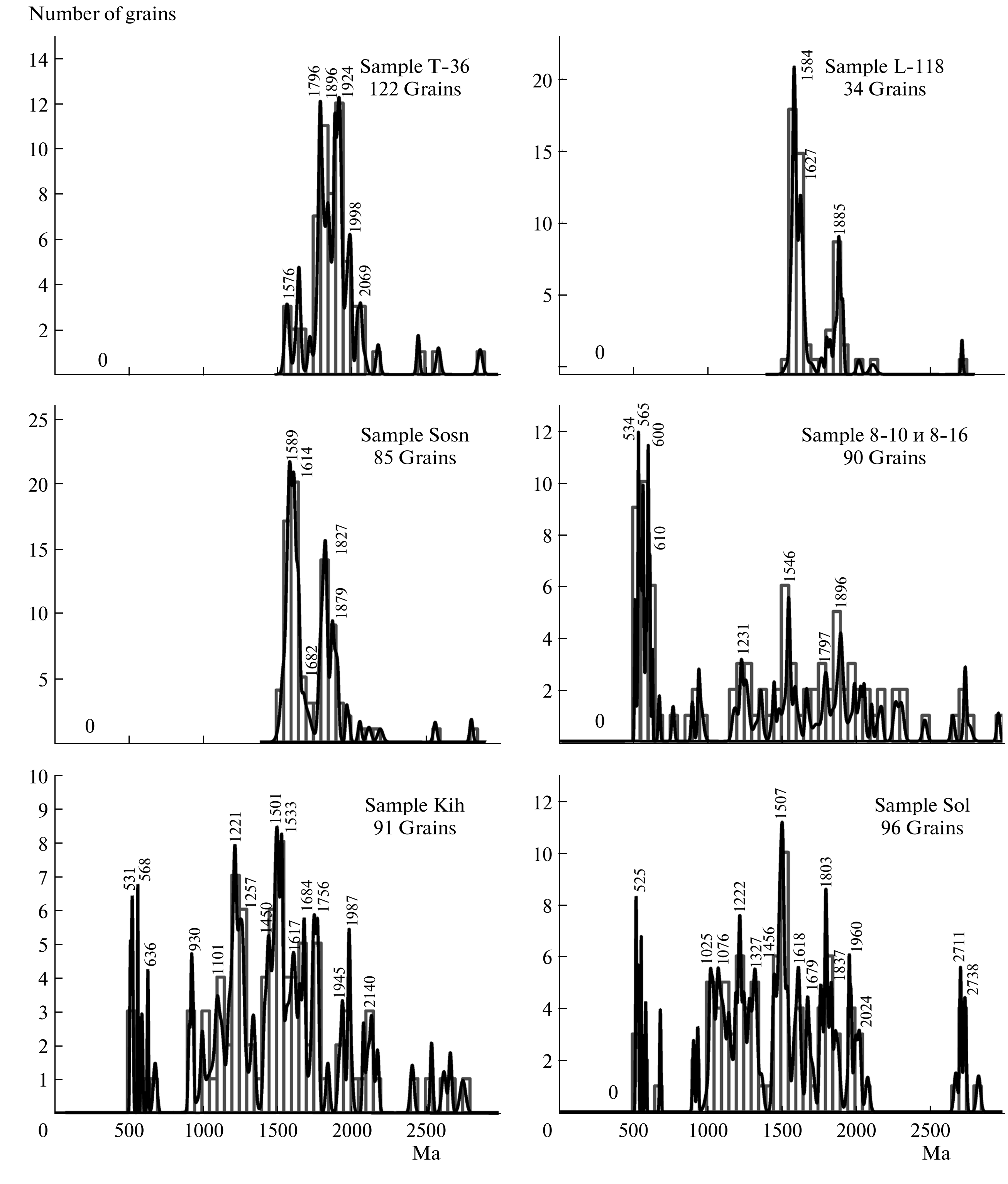

Fig. 3. Probability density plots with histograms of the obtained U–Pb ages of detrital zircon from the samples studied. Numbers note the ages of peaks (clusters of not less than three results), Ma.

total lack of zircons close in age to the time of sediment deposition. Notably, various stratigraphic levels of the Ediacaran section demonstrate somewhat different provenance age patterns, suggesting diverse source–rock complexes and their contribution to the sediments. For instance the Redkin Horizon sediments (sample T-36) demonstrate provenance age peaks at 2069, 1998, 1324, 1896, 1796, and 1576 Ma, while those of the Kotlin Horizon (samples L-118 and Sosn) are typically at about 1880, 1830, 1650, and 1600 Ma. All the obtained age peaks fit well the known ages of magmatic rocks, exposed in the south of the Baltic Shield [14], implying a dominant contribution of debris during the Ediacaran from that source.

The Lower Cambrian samples display a preponderance of Mesoproterozoic provenance ages, emergence of a considerable proportion of Neoproterozoic ages, and the presence of Early Cambrian zircons, closeto the depositional age. In the Baltic Shield, no Neoproterozoic or Early Cambrian magmatic events are known [14], while they occurred widely in the Timan–Pechora region [15]. It is most likely that those areas could be sources of detrital zircons of those ages, transported to the eastern part of the Baltic monoclise in the Early Cambrian. According to published data [9], the ages of rocks composing relics of the Timanian orogen are in the range of 750–510 Ma. The new data presented suggest that detrital zircons with the mentioned ages are present in the sediments of the Lomonosov, Lukatin, and Tiskres formations of the Lontovas and Lower Dominopol Horizons of the Lower Cambrian. Hence, at the boundary of the Ediacaran–Early Cambrian in the northwestern part of the Russian Platform, there was a significant change in the direction of clastic material transportation as well as a switch in provenance sources. During the Ediacaran the main debris source for the eastern part of the Baltic monoclise was the northerly located Baltic Shield, but then at the very beginning of the Cambrian (Lontovas and Dominopol time) along with input of clastic material, the area from the Timanian margin to the northeast of Baltica started to play an important role as a provenance area.

The newly obtained data imply transport of debris from the Timanian orogen to the eastern part of the Baltic monoclise during the Early Cambrian: this, in turn allows us to decrease the age limit of the Timanide formation: previously it was suggested to be Middle Cambrian (about 510 Ma [9]) on the grounds of the presence of a "Proto–Uralian–Timanian provenance–signal" in the Sablino Formation sediments (south Ladoga), but the new data shift it to the Early Cambrian, about 530 Ma.

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